Research on Occupant Safety in Frontal Collision Based on Different Sitting Positions of Intelligent Vehicles

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Abstract: To study the safety of drivers with different sitting positions in intelligent vehicle collision, the slide model of SUV was established and the precision of the model was verified by slide test. The simulation model of driver's attitude was established by THUMS. According to the results of post mortem human surrogate (PMHS), the sitting postures of THUMS at different seat backrest angles were adjusted and the drivers' injuries of three sitting postures in frontal collision were analyzed. Simulation results show that when the driver was in semi-recumbent and reclining posture, the protective effect of the airbag on the head was obviously reduced in collisions, and the head and chest will be seriously damaged due to the large seat backrest angle, resulting in increased distance between the head and the wheel. Besides, the tilting sitting posture leads to the risk of sunken seat in the collision. Therefore, with the development of autonomous driving technology, not only should intelligent vehicles meet occupants' comfort requirements, but the collision safety caused by the change of sitting postures should be considered.

Keywords: Collision safety, Intelligent vehicle, THUMS, Seat backrest angles.

1. INTRODUCTION

Automated Vehicles (AVs) are developing rapidly, advanced autonomous driving technology provides the possibility for the driver to change his sitting postures [1-4], creating more room for the legs, to be reclined fully, or tilted to provide more relaxed conditions for socializing and working [5-8]. As an important part of occupant restraint system, car seat's design should not only satisfy the occupant's comfort, but also consider the protective effect in collision. At present, the automotive seat collision safety is now designed in general at plumb face rear tilt 25°[9]. Compared with standard sitting posture in traditional driving environment, intelligent vehicles can allow drivers to have more comfortable posture choices by eliminating the need to interact with vehicle control. Therefore, it is necessary to study the impact of different sitting postures on occupant safety in intelligent vehicles [10-12].

Abroad researches in this field were started earlier, and Daimler Chrysler's research shows that occupant's sitting posture has close relationship with the protection effect of constraint system in collision. The most serious investigated factor in the frontal collision with reclined seats is submarining [13-14], the occupant's hips sliding under the lap belt causes severe injuries to the lumbar spine and internal organs [15-16]. Accident data analysis shows that the submarining phenomenon is the reason for many fatalities and serious injuries during a frontal impact [17-18]. The experimental studies in Literature [19] show that the combined acceleration of the head, chest (at T1), and pelvis is lower when the seat is in the foremost position than that when the seat is in the rearmost position. Literature [20] proposes to add seat cushion angle adjustment mechanism in the occupant restraint system to increase the included angle between seat cushion and the floor in case of traffic accidents, and use seat cushion to form effective restraint in front of the gravity center of the driver so as to reduce the driver's injury in collision. In literature [21], the overall occupant collision injury was reduced by 43% by optimizing seat backrest angle and occupant sitting posture. However, current researches are mainly carried out within the range of 15° reclining of the seat backrest angle, and there is a lack of research on occupant collision injuries under larger seat backrest angle in a more comfortable and relaxed sitting posture. Therefore, in order to study the collision safety of different sitting postures in intelligent vehicles, this paper took the driver's sitting postures in a certain vehicle as the research object and conducted bench-marking analysis on the simulation model through slide test. Combined with THUMS, which is more in line with the biological fidelity, this paper carried out the analysis and research on the occupant injury in frontal collision in different seat tilt angles.

2. METHODS

In order to analyze the impact of different driver's sitting postures on driver's injury in frontal collision,a restraint system simulation model including driver's

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seat, steering wheel, instrument panel, seat belt and airbag was established by taking the driver's position of an SUV as the research object. Among them, the limit force value of the safety belt is 3.5KN. Pre-tensioned belt and airbags are activated 15ms after the collision. Based on test conditions, a simulation model of the restraint system slide was established with Thor 50th male finite element dummy, and a collision waveform with a peak value of about 36g was applied, as shown in Figure **1**. The whole finite element model has 479753 nodes and 765780 units, as shown in Figure **2**.

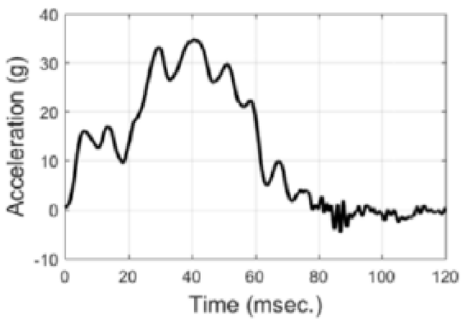

Figure 1: Frontal impact test waveform.

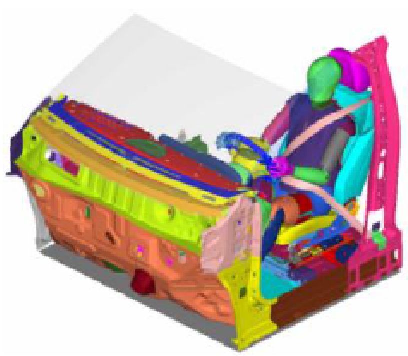

Figure 2: Simulation model of driver restraint system.

High-speed photography collected by the slide test is used to compare the images at different moments such as airbag expansion and the contact between the dummy and the airbag with the simulation animation, as shown in Figure **3**.

It can be seen that the airbag fully deploys at about 50 ms and begins to contact the dummy head. During the collision, the airbag normally deploys without unstable contact or dangerous deployment. In addition, the simulation animation is basically consistent with the airbag deployment time and the contact time of airbag and head in the test, indicating that the restraint system has a good protection effect on frontal impact and the simulation model has high accuracy. Secondly, the

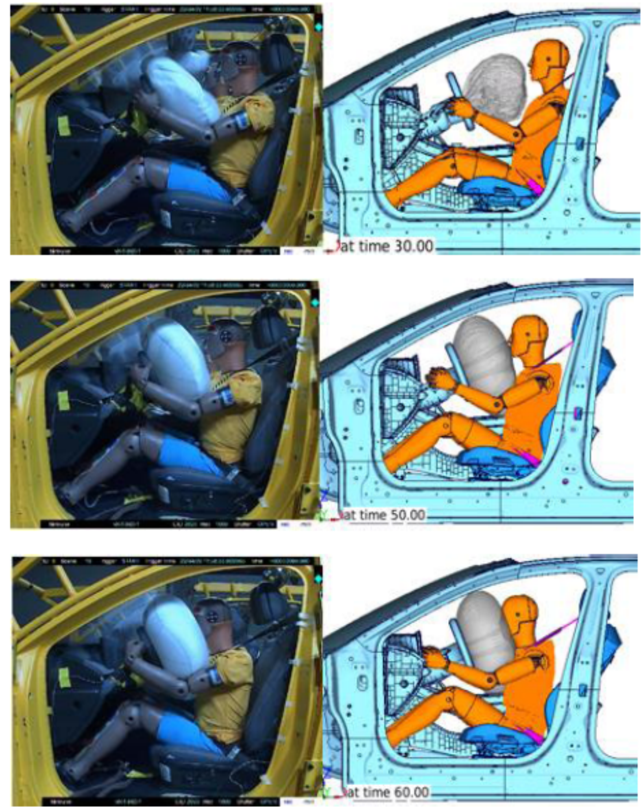

Figure 3: Comparison between frontal impact slide test and simulation.

performance comparison of the safety belt in the test and simulation is shown in Figure **4**.

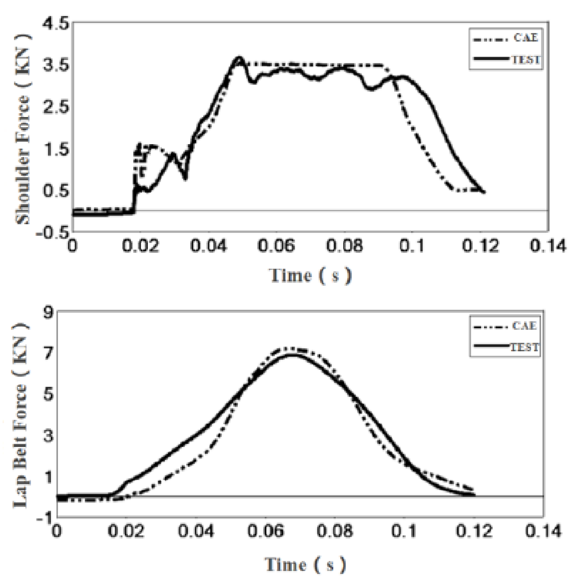

Figure 4: Comparison of seat belt forces in test and simulation.

It can be seen that the belt shoulder force and belt force curves in test and simulation fit well. Therefore, it is considered that the simulation model of the restraint system is effective and can be used for subsequent research and analysis.

Intelligent cars with high-level autonomous driving technology do not need human intervention in most scenarios, allowing drivers to take their hands off the steering wheel during driving and choose a more comfortable sitting posture. Moreover, seat manufacturers have studied zero-gravity seats with pelvic angles ranging from 128° to 145°. Therefore, as shown in Figure **5**, the normal sitting posture with a seat angle of 25°, the semi-recumbent sitting posture with a seat angle of 45°, and the reclining sitting posture with a seat angle of 60°were selected for study and analysis.

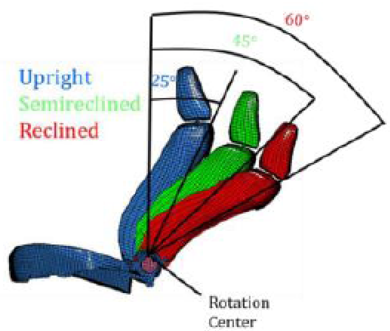

Figure 5: Backrest angles of different sitting postures.

The impact dummies used in traditional frontal collisions, such as Hybrid III and Thor dummies, are designed for standard sitting posture, and the dummies' pelvis cannot be expanded at a large angle. Therefore, this paper chooses THUMS human finite element model for simulation analysis. The dummies are designed and developed by Toyota Company, which can accurately represent the geometric characteristics and material characteristics of human body, with very precise anatomical structure characteristics, complex material model and high biological fidelity.

Refer to GEPNER *et al*. [22-26] cadaver test of occupant posture in tilting seats. As shown in Figure **6**, the semi-rigid seat was used in this test to replace the car seat. The seat plate was a 380mm wide rigid plate, and the backrest was composed of rubber wrapped rigid pipe strings and springs. The seat plate and the angle of the backrest were controlled by an adjustable articulated rigid plate. The seat plate is at 15° horizontal and the seat's backrest angle is initially set at 22° vertical.

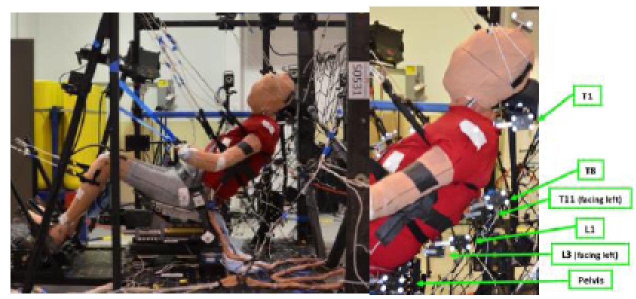

Figure 6: Cadaver test of sitting postures.

As shown in Figure **7**, according to the different parts angles measure standards of THUMS, record the angles of various parts of the body in different sitting postures by adjusting backrest angles, as shown in Table **1**.

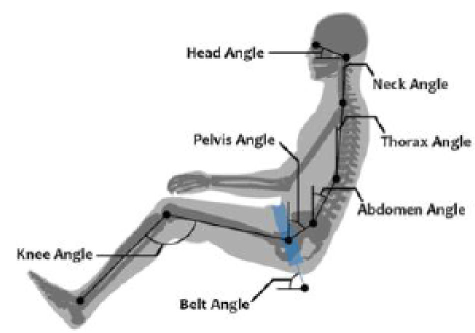

Figure 7: Angle positioning of various parts of THUMS.

Table 1: ANGLE Measurements of Various Parts of the Human Body Under Different Sitting Postures

Posture	Angle						
	Head	Neck	Chest	Abdomen	Pelvis	Knee	Belt
Standard sitting posture (25°)	39.3	23.3	22.2	46.5	59.5	111.7	89.8
Semi-recumbent sitting posture (45°)	38.2	22.6	23.1	46.0	69.1	1120.	91.5
Reclining sitting posture (60°)	39.8	23.8	22.6	48.7	77.5	109.5	91.7

As shown in Figure **8**, the posture of THUMS was pre-simulated according to the angles of each part of the occupant measured in the test, and constraint system simulation models of the three occupant sitting postures were established by combining seat models with different backrest angles.

Figure 8: Finite element models of different sitting postures.

3. RESULTS

Based on the driver restraint system model established above, simulation analysis of three different sitting postures was carried out. In the initial state, the dummy was sitting in standard posture with a backrest angle of 25°; secondly, the dummy was sitting in semi-recumbent posture with a backrest angle of 45°, and thirdly, the dummy was sitting in reclining posture with a backrest angle of 60°. Figure **9** shows the sequence diagram of frontal collision simulation with three different sitting postures.

It can be seen that in standard sitting posture, the airbag is fully deployed at about 50 ms. Under the action of seat belt Pre-tensioned and limiting force, the driver maintains a good posture. The upper body does not tilt forward significantly, and the airbag does not sweep the face during the process of deployment. The airbag plays a good buffer role in the contact with the head. In semi-recumbent sitting position with the seat backrest angle at 45°, the distance between the steering wheel and the head increases, resulting in a certain gap between the air bag and the head after full expansion, which fails to buffer the forward movement of the head the first time. In the late collision, the airbag cannot provide effective support as the dummy leans forward, resulting in "breakdown" phenomenon. In reclining sitting posture with 60° seat backrest angle,

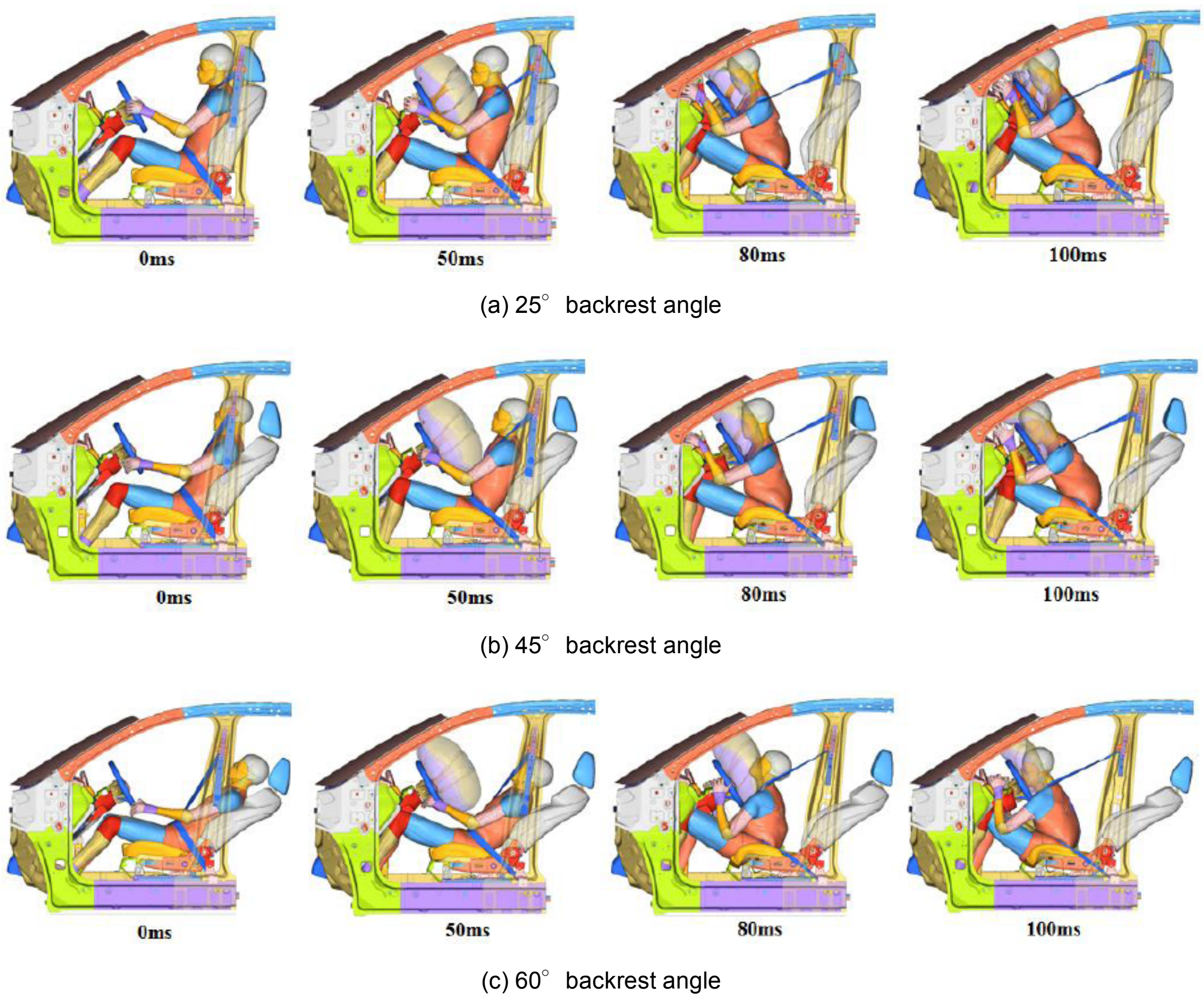

Figure 9: Collision simulation time sequence diagram of different sitting postures.

the distance between upper body and the steering wheel is bigger. In the process of collision, the dummy head mainly contacts with the lower part of airbag, which fails to provide effective support. Airbag "breakdown" phenomenon also appears in the late collision. In addition, because of the toppling posture, the space between the shoulder straps and the dummy's chest is too large, which can not play a good role in fixing the occupant posture, and may lead to sunken seat problems.

From the perspective of occupant injury, THUMS model evaluates the occupant injury risk by analyzing the stress and strain of the tissue structure in human body, which is different from the traditional crash dummy which evaluates the occupant injury through indicators like acceleration, and compression. For THUMS model, head injury is evaluated by intracranial pressure and skull stress value. Literature [27-28] points out that mild injury would occur when intracranial pressure is lower than 173 kPa, and moderate injury would occur when intracranial pressure is between 173 kPa and 235 kPa. Literature [29-30] indicates that skull fracture occurs when skull stress reaches 10.09 MPa. Figure **10** shows head injuries in front impact of three different sitting postures.

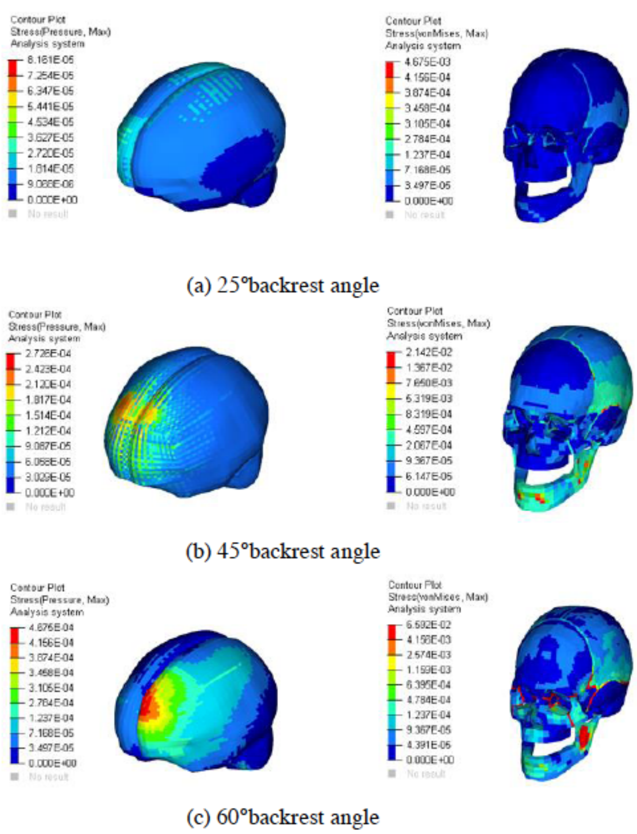

Figure 10: Head injuries in different sitting postures.

It can be seen that in standard sitting posture of 25°, the intracranial pressure of the head is 81.6 kPa, which is lower than 173 kPa, and only minor injuries will occur. The skull stress is 4.67 MPa, which is far lower than 10.09 MPa, and the probability of skull fracture is low. In semi-recumbent sitting position of 45°, the intracranial pressure of the head is 272.6 kPa, higher than 235 kPa, which leads to serious injury. The skull stress is 21.47 MPa, higher than 10.09 MPa, and the probability of skull fracture is high. In the reclining sitting position of 60°, the intracranial pressure of the head is 467.5 kPa, higher than 235 kPa, which leads to serious injury. The skull stress is 65.9 MPa, much higher than 10.09 MPa. The probability of skull fracture is very high, and the head will be seriously injured.

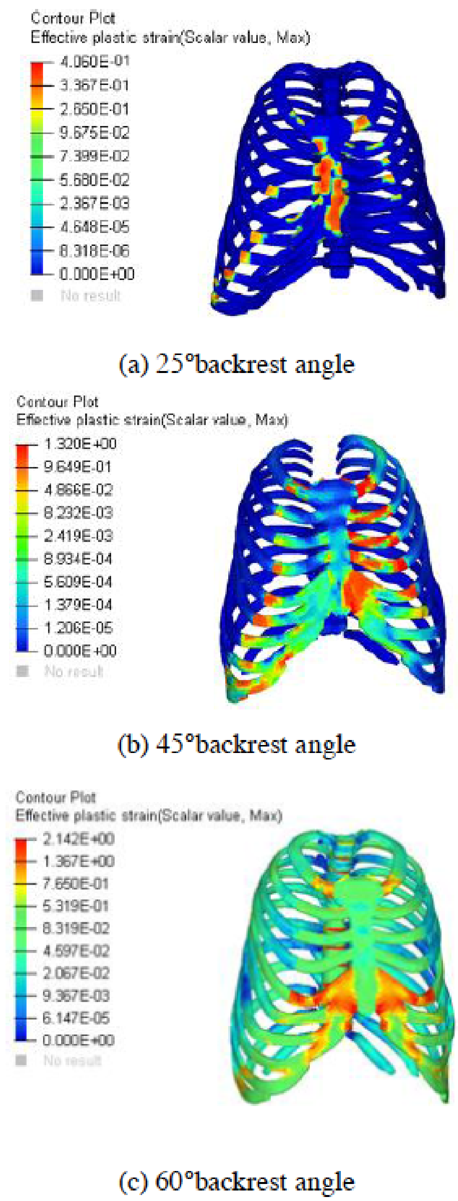

Figure 11: Chest rib injuries in different sitting postures.

As for THUMS, the chest injury is mainly determined by the plastic strain of ribs. Literature [31] shows that when the plastic strain of ribs is greater than 1.4%, the probability of rib fracture is very high. As shown in Figure **11**, the chest rib injuries of three different riding postures in frontal impact. It can be seen that in standard sitting posture of 25°, the plastic deformation of chest ribs is 40.6% , which is more than 1.4%, and chest ribs are prone to fracture. The plastic deformation of chest ribs is 132% in the semi-recumbent sitting posture of 45°, and chest ribs are prone to fracture. The chest injury increases 3.25 times compared with the standard sitting position. The plastic deformation of chest ribs is 214% in reclining sitting posture of 60°, which increases chest injury by 5.27 times compared with the standard sitting posture, and the chest would be seriously injured.

4. CONCLUSION

The simulation model of driver's postures was built by using the restraint system simulation model after bench-marking and THUMS. According to cadaver test results, the sitting posture of THUMS at different seat backrest angles was adjusted, and the occupant injuries of three sitting postures in frontal collision were analyzed. Simulation results show that when the occupant is in semi-recumbent and reclining postures, due to the large seat backrest angle, increased distance between the head and the wheel is caused, and the airbag's protection effect on the head in collisions is significantly lower, causing serious damage in head and chest. The tilt of sitting posture leads to the risk of sunken seat in collisions. Therefore, with the development of autonomous driving technology, not only should intelligent vehicles meet occupants' comfort requirements, but the collision safety caused by the change of sitting postures should be considered.

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